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ROCKS CONTIGUOUS WITH THE BASALTIC CUIRASS OF WESTERN VICTORIA

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Abstract

The 9000 sq. miles of volcanic rocks in W. Victoria were emplaced over some 15,000,000 years. Their numerous interfaces with sediments below and above are instructive both as to time and process (geologic and climatic). The tuffs and lavas seldom contacted the sea, so interfaces are commonly soils, which appear to be referable to 4 terrains:

1. Mid-Tertiary deeply kaolinized Nunawading Terrain.
2. Lower Pliocene lateritized Timboon Terrain.
3. ? Plio-Pleistocene krasnozems.
4. Mid-Pleistocene to present duplex and uniform soils.

In the Cainozoic there were two maxima of earth movements associated with the extrusion of the Older Basalts and the Newer Basalts respectively. The former period of movements is named the Bass Strait Epoch, and the latter has already been named the Kosciusko Epoch. The above 4 terrains appear to be useful for dating the movements of the Kosciusko Epoch where suitable fossils are not present. Some of the geological formations associated with the lava plain are briefly described, and some reasons given for the presence of quartz grains in soils on basaltic lavas and tuffs.

Introduction

Interfaces are important in many sciences and, in geology, the interfaces between formations are often most instructive. For the historical geologist they may yield information on process and may represent time expired. Thus the interfaces between the basaltic cuirass of W. Victoria and the contiguous rocks yield valuable information about the times of eruption, and the processes then going on. The study of these interfaces is complicated by the long period over which the volcanic rocks were emplaced, and by the vast area over which dissection has not yet exposed the pre-basaltic terrain.

The Upper Cainozoic basaltic rocks of W. Victoria constitute a shield or cuirass of some 9,000 sq. miles (Grayson and Mahony 1910) varying in thickness from a foot to over 200 ft. They consist entirely of basalts and basaltic tuffs. Just as the Lower Cainozoic basalts (called the Older Basalts) characterize E. Victoria, so the Upper Cainozoic Newer Basalts characterize C. and W. Victoria. But the two series are not mutually exclusive in distribution. Newer Basalts overlie Older Basalts, e.g. at Footscray, Essendon, Keilor and Maude, while at Waurn Ponds, W. of Geelong, pebbles of Older Basalt are included in Oligocene marine beds against which Newer Basalt has flowed.

The Older and Newer Basalts contrast in mode of eruption. Older Basalt dykes are very common, swarms of them being present in some areas, yet, although many streams have cut through the Newer Basalts to the underlying rocks, dykes of that age are unknown. On the other hand, eruption points for the Newer Basaltic volcanics are even more numerous than one would infer from the literature. On present evidence, therefore, the Older Basalts would appear to have been extruded mostly by dykes, but also by vents (Edwards 1934), while the Newer Basalt eruptions were by vent only.

The Newer Basaltic vulcanism of W. Victoria has been chiefly effusive, but in the final stage dominantly explosive yielding hundreds of tuff and scoria cones (some 250 have been counted so far) that characterize the present geomorphology of the lava plains. This period of vulcanism began in the Upper Miocene something like 15,000,000 years ago. Unless the evidence has been destroyed (and tuff is one of the most easily eroded rocks), most of the explosive phase has been limited to the past 15,000 years.

Period of Eruption

No Newer Basaltic vulcanism is known older than the very end of the Miocene; it continued until a few thousand years ago. The earliest activity so far discovered is that at Minhamite, 25 miles SE. of Hamilton. On Goodwood Station, where Spring Ck intersects the base of the basalt, tuff and richly fossiliferous marly marine sands outcrop immediately under the basalt (Fig. 1). The beds contain *Aturia australis*, a pelagic cephalopod, which genus is not known to exist later than the Miocene. Species of *Eucrassatella, Neotrigonia, Placamen* and *Zenatiopsis* (Gill and Darragh 1963) found there are at evolutionary stages comparable with the Cheltenhamian rather than the Kalimnan Stage (Lower Pliocene). The Minhamite fauna probably represents the upper part of the Cheltenhamian Stage, in other words, the end of the Miocene.*

[* Their age has been discussed with Mr T. A. Darragh.]

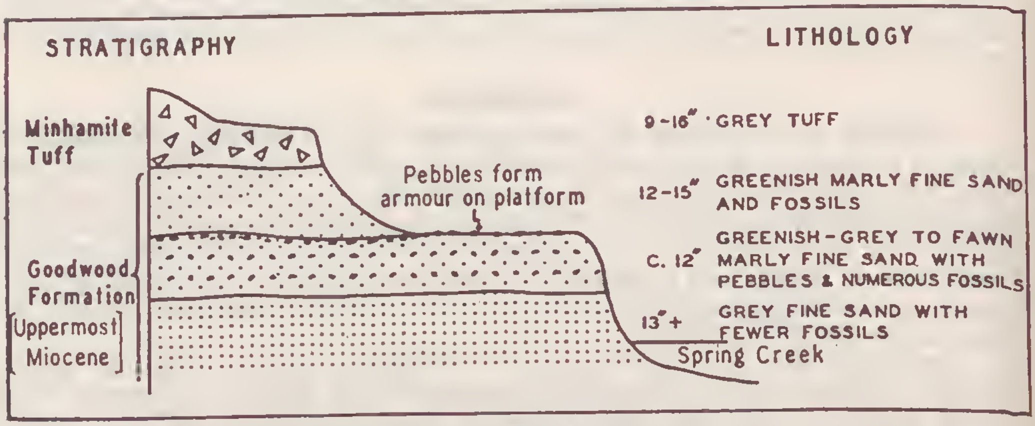

FIG. 1—Late Miocene marine strata beneath basalt at Minhamite, 25 miles SE. of Hamilton, Vic. Stratigraphic names here proposed.

That Lower Pliocene eruption took place can be proved at Muddy Ck 4 miles W. of Hamilton, where basaltic tuff occurs in marine beds of Kalimnan age (Gill 1957a, p. 162). Fig. 2 shows sections at Hamilton on Muddy Ck and the next creek to the N., Grange Burn. No tuff bed occurs on Grange Burn as it does on Muddy Ck, but tuff minerals occur in the fossil soil.*

[* On both creeks there is a duplex soil with abundant carbonate nodules in the B horizon (Gill 1955, p. 16). The fossil soil is overlain with basalt which at the surface is semi-lateritized, then later modified by krasnozem formation, followed by leaching of the top 12 in.—a polygenetic soil (Gibbons and Gill 1964). Under the basalt at Grange Burn are the stumps of a stand of Celery Top Pine (*Phyllocladus*), now extinct on the Australian mainland, but still growing in W. Tasmania and in New Zealand in temperate rainforest. *Phyllocladus* has been found under the basalt in a mine at Daylesford. The determinations are by Mr H. D. Ingle of CSIRO Division of Forest Products.]

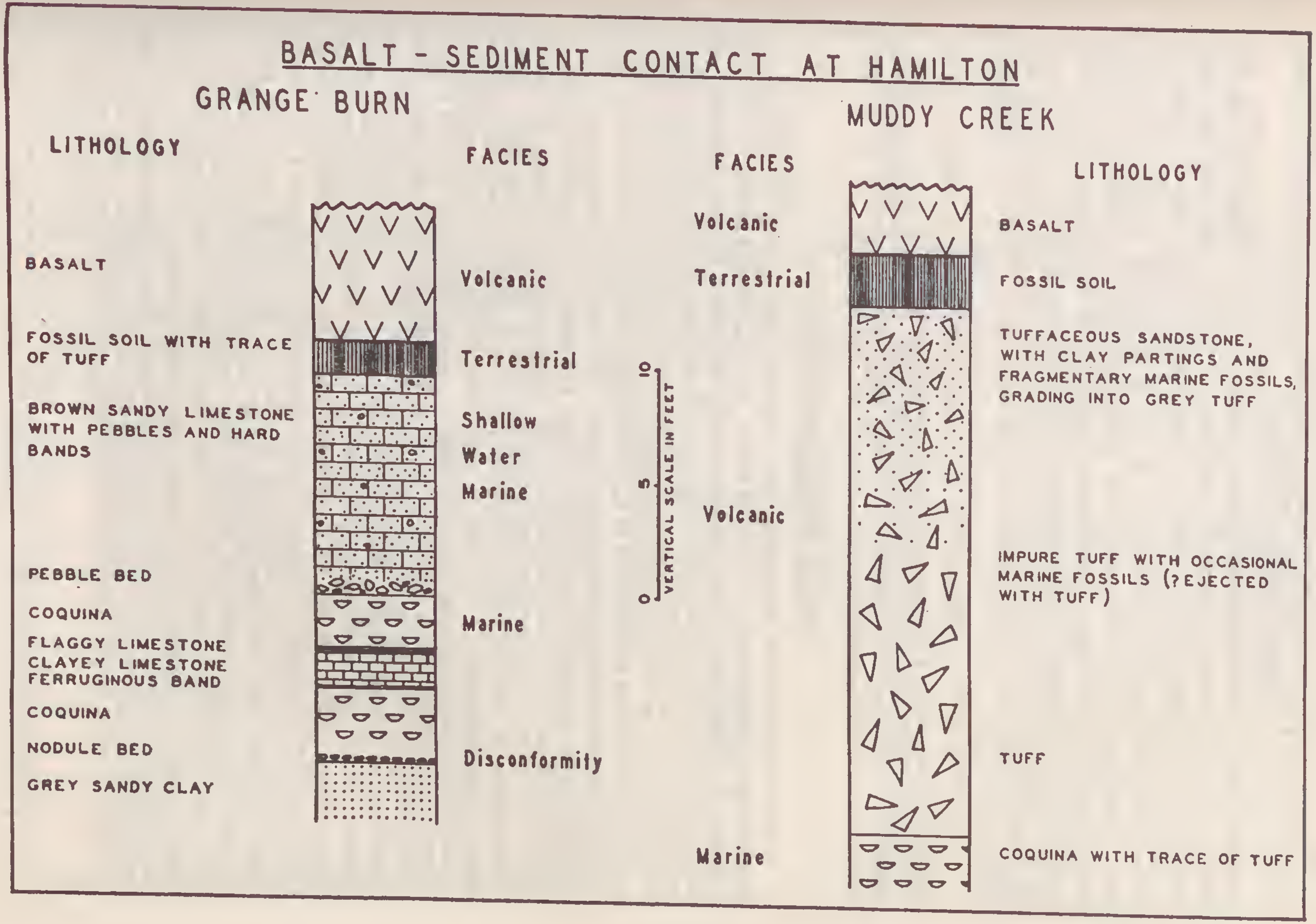
BASALT - SEDIMENT CONTACT AT HAMILTON
GRANGE BURN
LITHOLOGY
FACIES
BASALT
Volcanic
FOSSIL SOIL WITH TRACE OF TUFF
Terrestrial
BROWN SANDY LIMESTONE WITH PEBBLES AND HARD BANDS
Shallow Water Marine
PEBBLE BED
COQUINA
Marine
FLAGGY LIMESTONE
CLAYEY LIMESTONE
FERRUGINOUS BAND
COQUINA
NODULE BED
Disconformity
GREY SANDY CLAY
VERTICAL SCALE IN FEET
0
5
10
MUDDY CREEK
FACIES
LITHOLOGY
Volcanic
BASALT
Terrestrial
FOSSIL SOIL
TUFFACEOUS SANDSTONE, WITH CLAY PARTINGS AND FRAGMENTARY MARINE FOSSILS, GRADING INTO GREY TUFF
Volcanic
IMPURE TUFF WITH OCCASIONAL MARINE FOSSILS (?EJECTED WITH TUFF)
TUFF
Marine
COQUINA WITH TRACE OF TUFF

FIG. 2

Thus, the oldest evidences of vulcanism belonging to the Newer Basalt series in Victoria are late Miocene and Lower Pliocene.

No evidences of volcanic activity can be found at the present time. There are no active vents, no fumaroles, and no heat gradients in bores suggesting continued activity. There is, however, a group of volcanoes such as Tower Hill near Warrnambool, Mt Shadwell near Mortlake, Red Rock near Alvie, and the volcano containing L. Elingamite near Cobden that can be shown by their physiography and soils* to be among the youngest of the vents. At Tower Hill beach, a soil with marine shells (collected by the aborigines) and aboriginal implements lies just a little above the tuff; the shells gave a radiocarbon date of 4,315 ± 195 years B.P., which provides a minimum age for the cessation of the main ash vulcanism (Gill 1953a). At Mt Gambier, South Australia, nests of charcoal in the A horizon of the soil under the tuff gave a radiocarbon date of 4,830 ± 70 years (Fergusson and Rafter 1957).

[* On similar slopes of basaltic tuff in this area, the accumulation of maghemite in the soil has been found to be a function of time and so useful for dating.]

Present evidence indicates that the period of eruption was late Miocene to mid-Holocene. Thus, there are interfaces of many different ages between the complex of volcanics and the contiguous rocks.

Marine Rocks under Basalts

S. of the Dividing Ra., the basalt plain is usually underlain by marine strata of Cretaceous to Pleistocene age, while in the N. the underlying rocks are usually all non-marine. During the Upper Cretaceous and Paleocene the sea gradually encroached on W. Victoria. By the Oligocene the sea had covered extensive areas, including part at least of what is now the Otway horst, as is indicated by the marine rocks of that age at Waurn Ponds on the fringe of the Barrabool Hills, at Birregurra on the N. flank of the Otways, and at Kawarren, high in the Otways. However, some of the Otway area was land during the Tertiary as is shown by the presence of the mid-Tertiary deep kaolinization, and the Lower Pliocene lateritization (see below). Miocene beds are by far the commonest of the marine rocks underlying the basalts. Miocene marine rocks can be seen under the Newer Basalt in the valley of the Maribyrnong R. and its tributaries downstream from Keilor, where the Tertiary shoreline appears to have occurred on Older Basalt. Similarly, they underlie the basalts of the Werribee Plain, e.g. at Mt Mary or Green Hill (Murray 1884) where they can be collected from the ejectamenta; at Spring Hill brown coal mine (Parr 1942) which is 3½ miles WNW. of Mt Mary (Fig. 3); and at the old brown coal mines of the Altona district. Although the brown coal extends as far inland as Bacchus Marsh, the overlying marine beds do not extend that far (Thomas and Baragwanath 1950). In the valley of the Barwon R. and its tributaries in the Geelong district, extensive Miocene marine strata occur (Coulson 1932, Bowler 1963). Similarly Curdie R. farther W. has incised the basaltic terrain to reveal Tertiary strata. This river cuts in deeply in its headwaters, then flows marginal to the lava field before crossing the coastal plain, free of basalt flows, to enter the sea at Peterborough. One mile S. of Oil Well Corner (on the Warnambool-Cobden road ½ mile E. of South Ecklin), on the right bank of Curdie R., there is a small volcano not previously recorded. A bulldozer trench cut in the ejectamenta of this small hill recently revealed Miocene marine limestone, sandstone, and white clay brought up by the eruption (the occurrence was reported by Mr J. Halford of Laang).

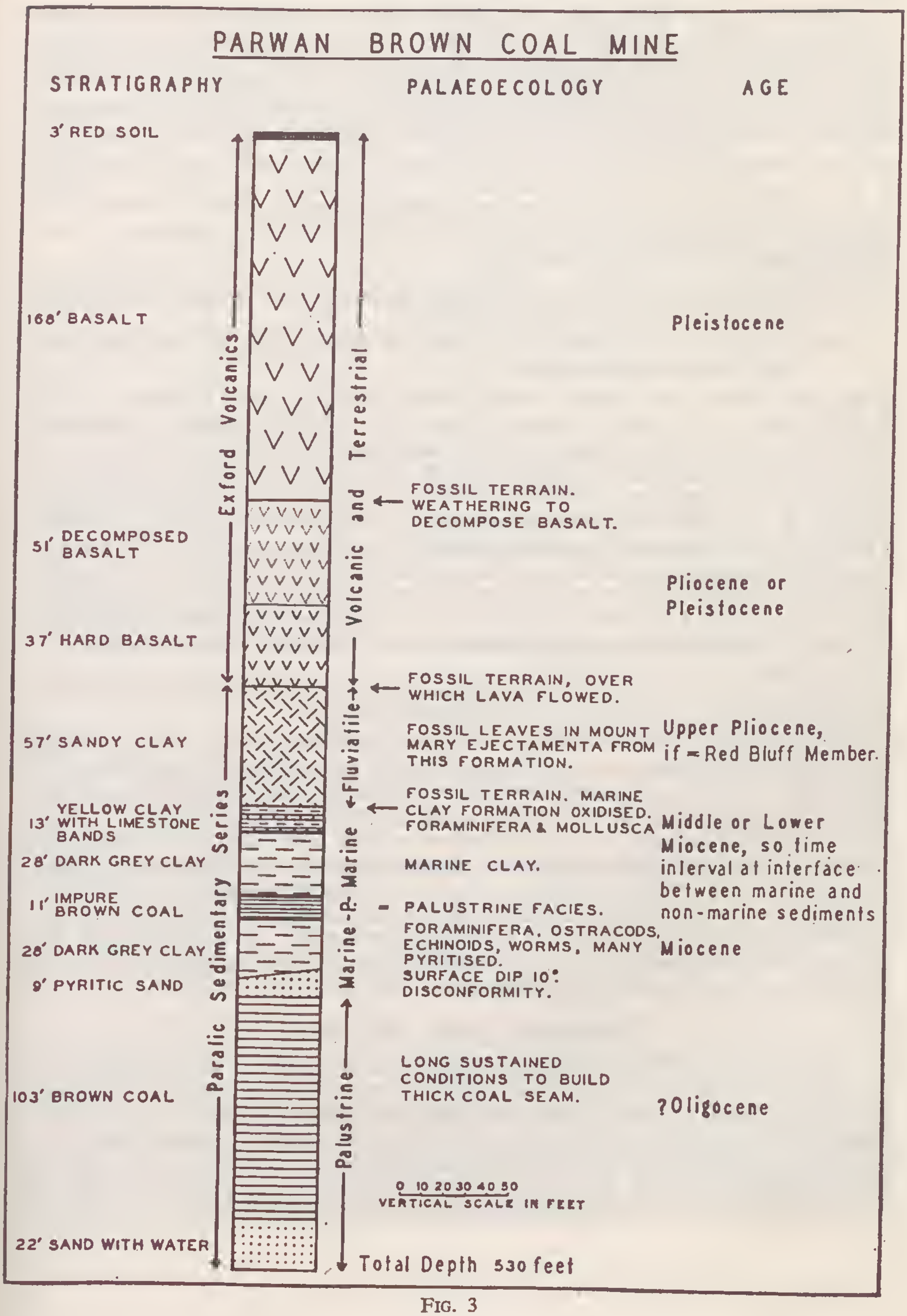
PARWAN BROWN COAL MINE
STRATIGRAPHY
PALAEOECOLOGY
AGE
3' RED SOIL
168' BASALT
51' DECOMPOSED BASALT
37' HARD BASALT
57' SANDY CLAY
13' YELLOW CLAY WITH LIMESTONE BANDS
28' DARK GREY CLAY
11' IMPURE BROWN COAL
28' DARK GREY CLAY
9' PYRITIC SAND
103' BROWN COAL
22' SAND WITH WATER
Exford Volcanics
Paralic Sedimentary Series
Volcanic and Terrestrial
Fluviatile
Marine-P-Marine
Palustrine
FOSSIL TERRAIN. WEATHERING TO DECOMPOSE BASALT.
FOSSIL TERRAIN, OVER WHICH LAVA FLOWED.
FOSSIL LEAVES IN MOUNT MARY EJECTAMENTA FROM THIS FORMATION.
FOSSIL TERRAIN. MARINE CLAY FORMATION OXIDISED. FORAMINIFERA & MOLLUSCA
MARINE CLAY.
PALUSTRINE FACIES.
FORAMINIFERA, OSTRACODS, ECHINOIDS, WORMS, MANY PYRITISED. SURFACE DIP 10°. DISCONFORMITY.
LONG SUSTAINED CONDITIONS TO BUILD THICK COAL SEAM.
Pleistocene
Pliocene or Pleistocene
Upper Pliocene, if = Red Bluff Member.
Middle or Lower Miocene, so time interval at interface between marine and non-marine sediments
Miocene
?Oligocene
0 10 20 30 40 50
VERTICAL SCALE IN FEET
Total Depth 530 feet

FIG. 3

Miocene marine fossils have been found in the ejectamenta of Mt Porndon (Skeats and James 1937), Red Rock NW. of Colac, Mt Noorat, Wangoom Hill (found by Mr L. K. M. Elmore), Bradshaw's Hill at Terang, Mt Shadwell near Mortlake, and Tower Hill near Warrnambool. From Mt Shadwell, Mr Brian Campion collected gasteropods including *Bathytoma rhomboidalis*, a turrid, the scaphopod *Dentalium* (*Fissidentalium*) *mantelli*, a coral *Trochocyathus*?, foraminifera and ostracoda. Mr D. Burns found marine Tertiary fossils occurring as casts in a tuff underlying basaltic ejectamenta at the S. end of L. Colac (mentioned further in discussion of lacustrine and palustrine sediments). Miocene marine beds have been recorded from Rokewood, 10 miles NNE. of Cressy (Dennant 1899). In this paper two localities are recorded:

(a) 'From the bores about a mile south of Rokewood, in the parish of Kuruc-a-ruc'. . .'collected by Mr A. M. Howitt.'
(b) 'The junction of Ferrer's Creek with the Woady Yallock, and thus about four miles north of Cressy.'

It may be that the two separate small samples in the Dennant Collection in the National Museum of Victoria marked 'Rokewood' come from these two localities.

Dr A. N. Carter kindly examined the samples, and also reported that the old bores near Rokewood went through clay with angular quartz, basalt, carbonaceous clay, sandy mottled clay, fossiliferous marine sediment, and Lower Palaeozoic bedrock, in that order. Dennant's first specimen (Reg. No. P16413 NMV) provided a fragment of *Nodosaria* cf. *annulata*, small button-shaped colonies of bryozoa, a fragment of a calcareous worm tube, the operculum of a small gasteropod like that of *Astraea, Turritella*, a pyrenid, *Limopsis* and *Nuculana*. The second sample (P16414) contained *Cibicides mediocris, Limopsis*, and some fragments of bryozoa. Dr Carter concluded that, on the evidence of the *Cibicides*, the age is Middle or Lower Miocene.

Miocene marine rocks also outcrop under the volcanic ejectamenta of L. Bullenmerri, L. Gnotuk, L. Keilambete and at Tower Hill.

In the Portland district, basalt flows are associated with marine strata belonging to the Maretimo Member and the Werrikoo Member of the Whaler's Bluff Formation (Boutakoff 1963); the Pliocene-Pleistocene boundary is placed at the base of the latter (Gill 1957b, 1961a). These basalts have deep krasnozems developed on them over a considerable area, but in the writer's opinion such soils are not related to present conditions or they would occur much more widely on Pleistocene basalts. Evidence of their relict nature is provided by the leaching of the top 12 to 15 in. with the development of minute nodules of magnetic iron oxide (maghemite).

Marine rocks under basalt flows provide a maximum age for them, but also indicate changes in conditions, for the basalts seldom rest directly on the marine rocks but have interposed a non-marine formation and/or a fossil soil.

Non-Marine Rocks under Basalt

The Kosciusko Epoch of earth movements (Andrews 1910) raised the Dividing Ra. and the Otway horst to their present elevations, so that the sea retreated from the area of plains S. of the Divide. This uplift began slowly in the Upper Miocene, but the pronounced movements were in the Upper Pliocene and Lower Pleistocene; movement continues, but on a minor scale. The uplift caused piedmont deposits to be washed out over the plain, while the rejuvenated rivers spread their sediments over a wide area. The non-marine sediments thus produced consist of clayey sands to sandy clays, i.e. poorly sorted and poorly washed sediments. Over most of SW. Victoria these deposits were buried by basalt flows and ash spreads. They were lateritized in places. Towards the W., as the Murray Gulf is approached, the movements were less severe and Lower Pliocene (Kalimnan) marine beds there cover Miocene strata. Due to the Kosciusko uplift, no post-Kalimnan Pliocene marine beds are known in Victoria (except for the very late Pliocene Maretimo Member), but they have been found on Flinders Is. in Bass Strait (Gill 1962a).

Fossil Soils Beneath and on the Basalts

Fossil soils are common at the lower interface of basalts and tuffs, but they have seldom been recorded. Four successive phases of pedological activity can be distinguished on the terrains buried by the basaltic and associated deposits. These fossil soils are products of different climates at different times and so can be used for dating; they make possible a determination of approximate age in non-marine deposits where at present there is no other method of dating.

Mid-Tertiary Deep Weathering

Attention has been drawn already to the very deep weathering of the Nillumbik Peneplain (Gill 1961b, Fig. 3). The rocks are kaolinized from 30 to 150 ft deep. The brick and tile works of Melbourne are based on this terrain, and the maximum depth of their quarries is usually the maximum depth of kaolinization at the site. In the railway cuttings on each side of Camberwell railway station, Melbourne, strongly kaolinized Silurian rocks occur. Over the eroded surface of this formation are lateritized late Miocene(?) clayey sands, demonstrating the relative ages of the kaolinized and lateritized terrains.

The relationships of both the Newer Basalt and the Older Basalt to this zone of weathering is shown in Fig. 4, which is a semi-diagrammatic section across the Moonee Ponds Ck just N. of Reynard's Rd and E. of Strathmore railway station (see Hanks 1934, p. 145). The Older Basalt is marked on Quarter Sheet 1 NW. as a dyke, but it is part of a flow. The Newer Basalt forms the plain into which the stream has cut. Beneath are the non-marine clayey sands that form a considerable delta at Melbourne (the Red Bluff Member of the Sandringham Sands, Gill 1957a). Beneath the Red Bluff sediments is the kaolinized terrain and, at this point, Older Basalt has been reduced to kaolinite (kindly determined by Mr A. J. Gaskin), sub-basaltic sands leached so that plant fossils are reduced to impressions, and the Upper Silurian bedrock kaolinized. At Minifie's wheat silos, Lennon St, S. Kensington, the foundations consist of kaolinized Older Basalt resting on a white claystone consisting of kaolinite (determined by Mr A. J. Gaskin), with a moderate amount of quartz, and a trace of mica. This is the same terrain where it is inclined into the Port Philip Sunkland on the Melbourne Warp (Gill 1961b). Where Dry Ck enters the Maribyrnong R. at Arundel, a mile N. of Keilor, sections in quarries and in the river bank show the kaolinized surface well. Both the Older Basalt and the underlying Silurian marine strata are affected. The kaolinization of the granodiorite at Bulla (Gaskin 1944) is due to this same event.

This same kaolinized terrain can be recognized at various places W. of Melbourne, e.g. Bacchus Marsh, Brisbane Ra., and at Colac where the brick pit is situated in kaolinized Lower Cretaceous rocks. Similarly, E. of Melbourne, areas of kaolinization and bauxitization have been recorded, e.g. at Mirboo North where Older Basalt and Lower Cretaceous freshwater sediments are involved (Raggatt

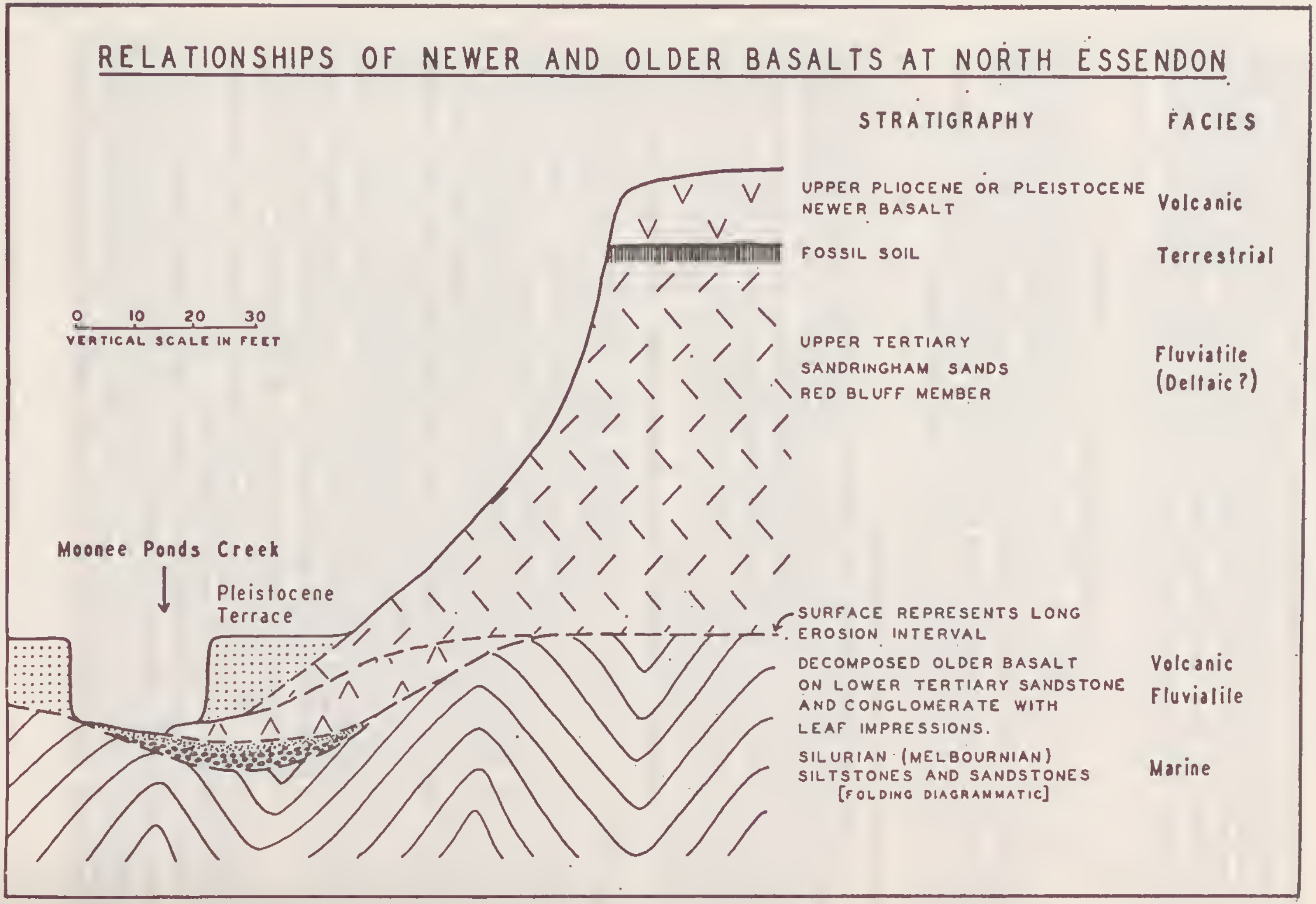
RELATIONSHIPS OF NEWER AND OLDER BASALTS AT NORTH ESSENDON
STRATIGRAPHY
FACIES
UPPER PLIOCENE OR PLEISTOCENE NEWER BASALT
Volcanic
FOSSIL SOIL
Terrestrial
0 10 20 30
VERTICAL SCALE IN FEET
UPPER TERTIARY SANDRINGHAM SANDS RED BLUFF MEMBER
Fluviatile (Deltaic?)
Moonee Ponds Creek
Pleistocene Terrace
SURFACE REPRESENTS LONG EROSION INTERVAL
DECOMPOSED OLDER BASALT ON LOWER TERTIARY SANDSTONE AND CONGLOMERATE WITH LEAF IMPRESSIONS.
Volcanic
Fluvialile
SILURIAN (MELBOURNIAN) SILTSTONES AND SANDSTONES [FOLDING DIAGRAMMATIC]
Marine

Fig. 4

et al. 1945, Owen 1954, Bell 1960). The kaolinization is believed to result from severe leaching under a tropical or subtropical rainforest (Gill 1961c, d).

As so many quarries show this ancient soil to advantage in the City of Nunawading on the E. side of Melbourne (e.g. Robertson's tile works), this terrain is here named the **Nunawading Terrain or Surface.** A distinction is made between the exhumed fossil plain known as the Nillumbik Peneplain, which precedes the Older Basalt, and the Nunawading Terrain which is a land surface younger than the Older Basalt on that peneplain. The original surface of the Nunawading Terrain over the Nillumbik Peneplain was probably to a large extent sands and gravels which have since been stripped away.

The Nunawading Terrain can be traced into New South Wales, South Australia and Tasmania. At Launceston in N. Tasmania, e.g., this terrain does not extend beneath the Paleocene-Eocene deposits in the Tamar Graben, as formerly thought, but is later than them, kaolinizing the sediments for a hundred feet or so, as is shown in the brick pits at Prospect and King's Meadows, and in the core of a bore at the Talbot Rd reservoir. When the dolerite and overlying sediments are horizontal, as at Prospect, they are kaolinized, but where they are well drained by dip, as at St Leonard's, or by faults, as at First Basin, they are bauxitized. Thus, where the silicic acid is drained away bauxite is formed and, where not, kaolinite is formed. This environmental consideration could guide future prospecting for bauxite in high latitudes.

The mid-Tertiary Nunawading Terrain has been found useful for dating, though it needs to be discriminated from the pallid zone of the laterite about to be discussed. Along the aqueduct that runs into the reservoir on Stony Ck on the top of the Brisbane Ra., the Ordovician slates are thoroughly kaolinized; such impervious rocks are not easily altered in this way. Over the top of this Nunawading Terrain at this locality are Kosciusko clayey sands which have been lateritized. The Rowsley fault and associated faults bound the Brisbane Ra. to the E., causing the above beds to be well drained; the fossil soils could not be formed in the beds as at present uplifted, and so must pre-date the faulting.

Lower Pliocene Lateritization

Equally widespread as the Nunawading Terrain, but of later age (proved by superposition and by the age of the marine beds affected), is a zone of laterization. This type of fossil soil may be seen in the Timboon railway cutting W. of L. Bullenmerri. Similar lateritic profiles have been located in many places in W. Victoria (often beneath the basalt plain), New South Wales, South Australia and Tasmania. In Victoria, marine rocks of many ages have been lateritized, but none younger than Cheltenhamian (uppermost Miocene) as at Beaumaris, Red Bluff (Gill 1963a), Royal Park, and the Maribyrnong R. valley. Lateritized areas and the Lower Pliocene marine beds are mutually exclusive in distribution and therefore thought to be contemporaneous. The Upper Pliocene basalt at Hamilton (which overlies a Lower Pliocene marine bed) is semi-lateritized (Gibbons and Gill 1964); this is apparently due to fading out of lateritizing conditions. 'Laterite' is used in many senses, even to include buckshot gravel. The term is used here for a profile of deep weathering 10 to 50 ft) with development of a thick ironstone layer (2 to 10 ft). This widespread and well-defined fossil terrain is here named the **Timboon Terrain or Surface** from its typical development in the Timboon railway cutting W. of L. Bullenmerri and S. of the Princes Highway (see Gill 1953b). At this, the type locality, it is underlain by non-marine clayey sands below which are Miocene marine beds (Fig. 5).

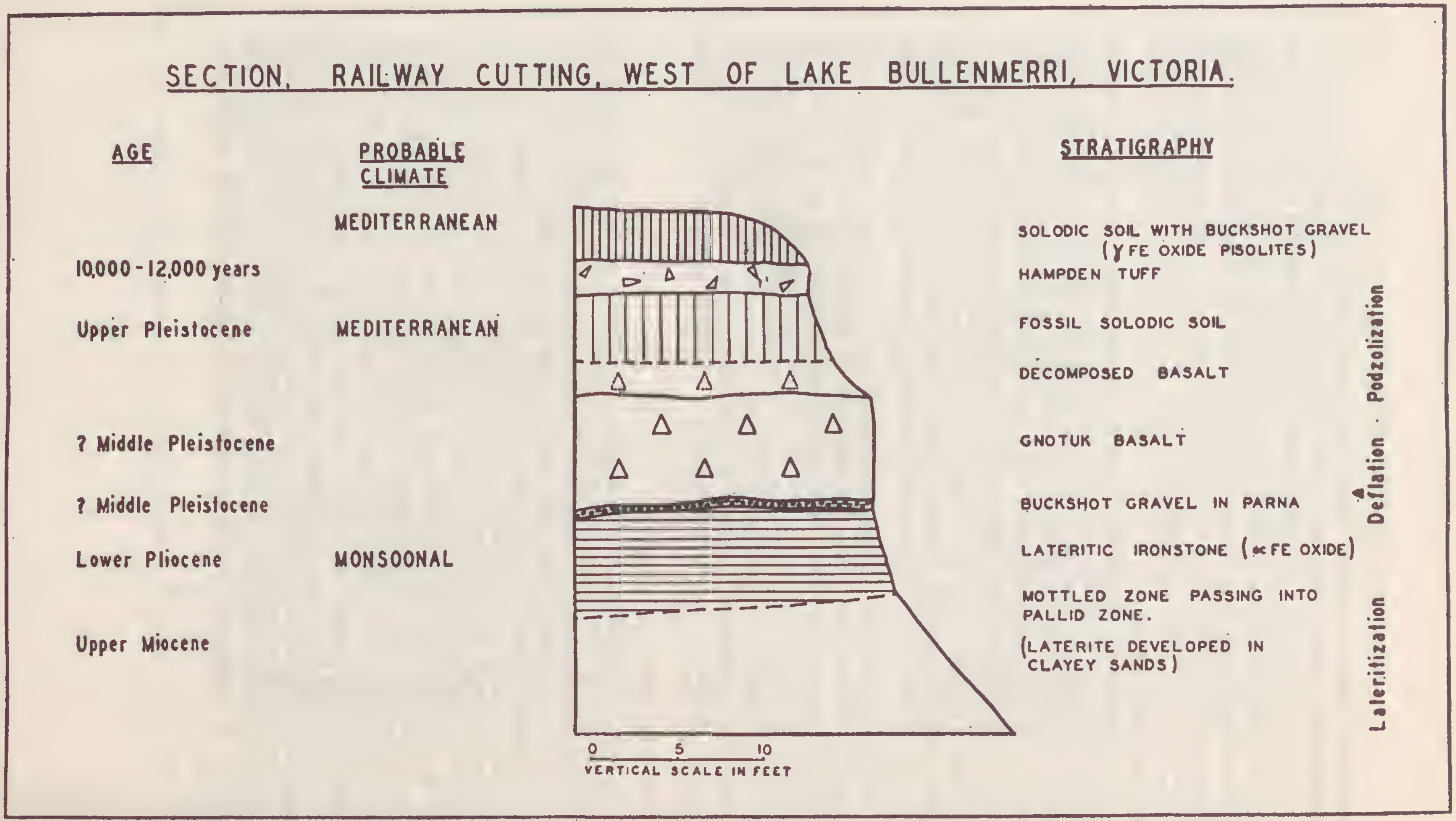
SECTION, RAILWAY CUTTING, WEST OF LAKE BULLENMERRI, VICTORIA.
AGE
PROBABLE CLIMATE
STRATIGRAPHY
MEDITERRANEAN
SOLODIC SOIL WITH BUCKSHOT GRAVEL (γ FE OXIDE PISOLITES)
10,000 - 12,000 years
HAMPDEN TUFF
Upper Pleistocene
MEDITERRANEAN
FOSSIL SOLODIC SOIL
DECOMPOSED BASALT
? Middle Pleistocene
GNOTUK BASALT
? Middle Pleistocene
BUCKSHOT GRAVEL IN PARNA
Lower Pliocene
MONSOONAL
LATERITIC IRONSTONE (α FE OXIDE)
MOTTLED ZONE PASSING INTO PALLID ZONE.
Upper Miocene
(LATERITE DEVELOPED IN CLAYEY SANDS)
Podzolization
Deflation
Lateritization
0
5
10
VERTICAL SCALE IN FEET

FIG. 5

Immediately above the laterite shown in Fig. 5 is a layer consisting essentially of fawn silt and magnetic buckshot gravel. Fig. 6 shows that, in grain size, these two materials are strongly contrasted; it is essentially a bimodal sediment consisting of—

(a) A loess- or parna-like oxidized silt interpreted as the product of soil deflation. Grain size analysis shows it is mostly wind-borne. The small amount of coarser material was probably saltatory.

(b) The maghemite-bearing pisolites (buckshot) are produced only in a duplex soil like that existing on the present surface of the Hampden Tuff at that site; a soil must have been broken down to provide this material.

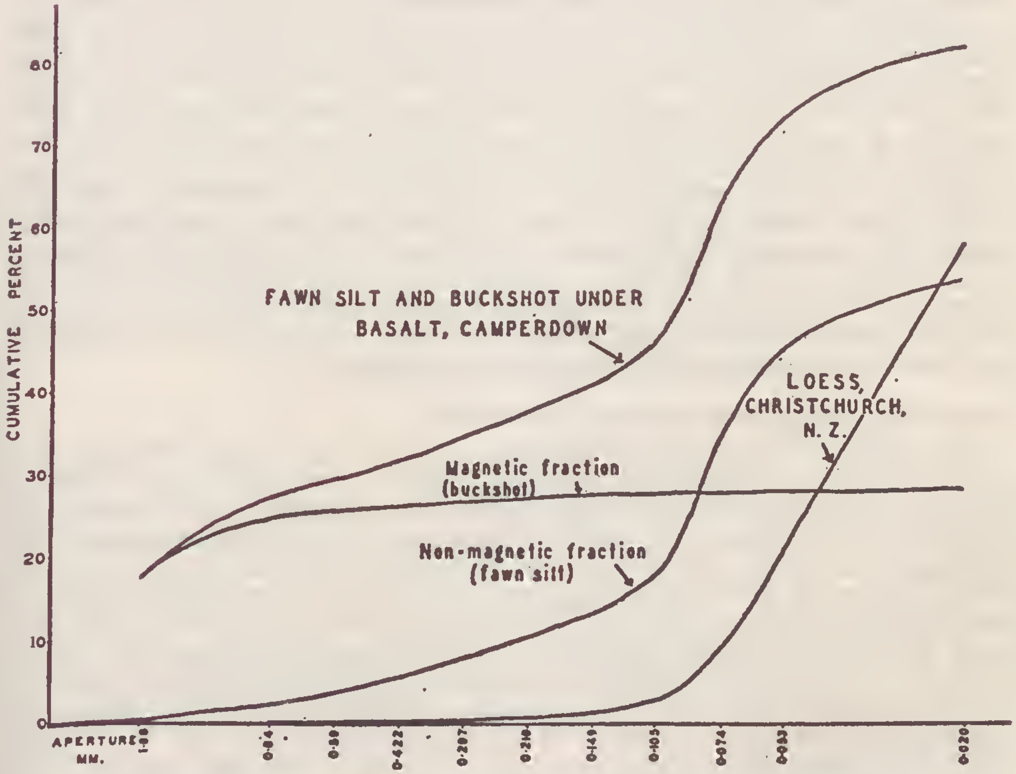

FIG. 6—Grain-size analysis of layer between laterite and basalt in the Timboon railway cutting. Analysis by the same laboratory of a loess from Christchurch, N.Z., is provided for comparison with the silt. Analyses carried out by Mr H. A. Stephens of the Foundry Sands Group of the CSIRO Division of Applied Mineralogy.

This deposit has been traced along the railway cutting for a few hundred yards. While maintaining its essential character, the bed shows variation due to inclusion of other material, including pieces of lateritic ironstone. It is most unlikely, if not impossible, that both the buckshot and the 'parna' were produced where they were found. It is envisaged that a solodic soil produced the buckshot at this general locality; this involves a fair rainfall to carry out the leaching. This soil may have developed in detritus from the breakdown of the laterite. The wind-borne silt fraction implies the breakdown of a soil or the desiccation of a lake floor from which the silt fraction was transported by the wind to the locality where it is found now. So, following on a period of climate like the present when buckshot was developed, there was a dry period when the terrain was desiccated. It is thought that the buckshot was derived from the local desiccation while the silt was brought in from a source farther away. If a dry climate occurred now, and the soil on the Hampden Tuff were desiccated, a layer of buckshot would be left.

A third character of this deposit needs to be explained, namely, the complete mixing of silt and buckshot. The deflation that left the buckshot would remove any silt and clay size material, but could leave some sand. Buckshot left behind by water erosion is not so clean and is characterized by its unsorted condition. On the other hand, when buckshot is left as a deflation product, it is clean and lying in a layer more or less one pisolite thick. The deposit under consideration consists of clean buckshot, not one pisolite thick but thoroughly mixed through the silt so that, generally, the pisolites are not touching one another. To lift the buckshot from occurring as a layer to being mixed so thoroughly can occur probably by only one process—water action. Dr E. C. T. Chao suggested that rain caused the silt and pisolites to form a slurry which flowed slowly down the low declivities of the terrain, mixing them thoroughly together. A search was made for similar materials on the extant terrain; they were found on the Port Campbell coastal plain (but not in the valleys cut therein) on the N. side of the Ocean Rd about ¾ mile W. of the township, and also on the E. side near the Waarre pine plantation.

? PLIO-PLEISTOCENE KRASNOZEM FORMATION

Krasnozems occur on the basalts associated with the marine Maretimo and Werrikoo Members of the Whaler's Bluff Formation at Portland (Boutakoff 1963). Gill (1957b, 1961a) places the Pleistocene lower boundary at the base of the Werrikoo. In the Portland area, these krasnozems (the 'laterite' of Boutakoff) can be demonstrated to be older than Pleistocene aeolianite, and they also show modification in that the top 12 to 15 in. have been leached so that they are lighter in colour, the clay content is reduced, and they have minute maghemite pisolites in them. This surficial leaching is interpreted as a Quaternary podsolization of the surface of the krasnozem. As krasnozems consist of little more than kaolinite and iron oxide (very stable materials), it is not surprising that they are difficult to modify. At Tarrington (allotment 4 of 12, Par. of S. Hamilton) in W. Victoria, Mr F. R. Gibbons showed me a krasnozem overlying a deep weathering of basalt described as a semi-lateritization. It was noted that here also the top foot or so has been further leached. A later flow of basalt occupies a valley cut in this terrain.

This same leaching of the top 12 to 15 in. of krasnozems has been noted in C. Victoria and E. Victoria. Krasnozems may also show signs of erosion over a considerable period (observations at Lilydale by A. M. Gill and writer). Although the age or ages of krasnozems in Victoria have not been worked out in detail as yet, it seems likely that they are a product of conditions following the period of laterization but before the present types of soils began to develop under a Mediterranean (in the broad sense) type of climate.

Further evidence for this interpretation is provided by a large section forming the N. end of the Standard Quarries pit in Wearing St, Footscray, a suburb of Melbourne. This is shown in Fig. 7, where a krasnozem has been formed on deeply weathered Older Basalt (a function of the Nunawading Terrain) of probable Oligocene age.*

[* A palynological analysis by Dr Isabel Cookson of carbonaceous sediments from between flows of Older Basalt in the Yarra Delta nearby gave a Yallournian age. The sample was obtained by the writer from a bore on Coode Is. put down by the Melbourne Harbour Trust Commissioners in 1950. Dr A. B. Edwards identified the basalt as an olivine type of uncertain affinities, but possibly Mooroodue Type Older Basalt.]

The soil developed on the Older Basalt is red and uniform (not duplex). It is overlain by a grey clayey sand which thickens towards the valley floor and ultimately replaces the krasnozem. The basalt-soil interface can be followed for a considerable distance in the quarry; the S. wall transects the former valley wall again. In between, the contact is along a flat plane, apparently the floor of the valley. A few remains of woody plants normal to the soil surface suggest it is a terrace and not the thalweg. Thus, a krasnozem was formed on the strongly decomposed Older Basalt, and this was followed by a different type of soil formation before the three or more flows of lava filled the ancient valley. As the valley is cut in the Timboon Terrain (i.e. through the laterite at Royal Park, Essendon and Keilor), the krasnozem is post-laterite. On the other hand, the Newer Basalt that buried the krasnozem has areas of deep montmorillonitic clay on it, showing that it is older than Holocene in age. The krasnozem could be Lower Pleistocene, similar in age to that at Portland.

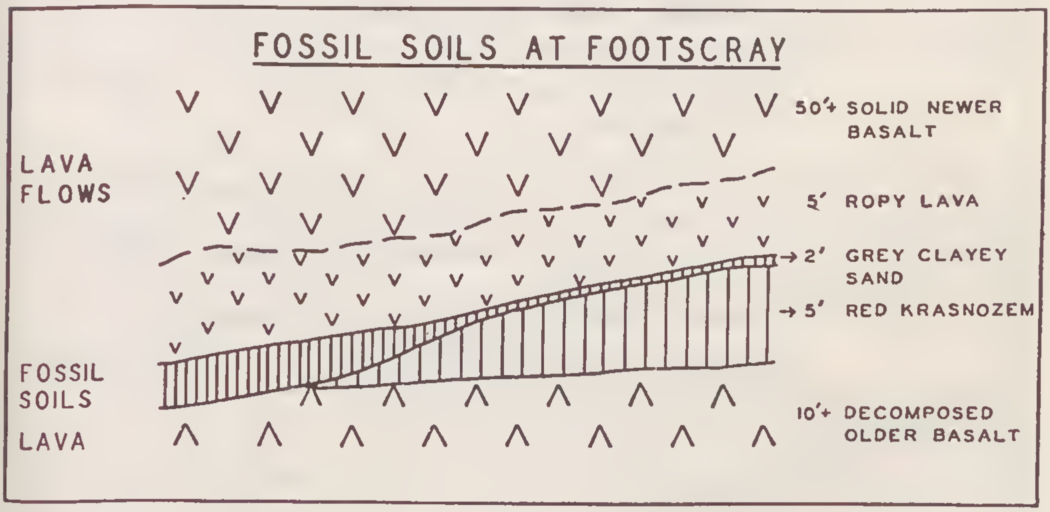

FIG. 7

QUATERNARY DUPLEX SOILS AND LOAMS

Holocene soils on basaltic ash spreads and lava flows in W. Victoria consist of juvenile soils or minimal duplex types if on tuff under good soil-forming conditions. Tuffs are the most easily weathered volcanic materials; duplex soils with pea-sized buckshot gravel* are found on spreads of late Pleistocene tuff. Soils on basalt flows

[* By buckshot gravel is meant magnetic pisolites rich in gamma iron oxide (maghemite). In the W. District the ironstone gravel from the breakdown of laterite is often called buckshot gravel by the farmers, but the iron therein is the non-magnetic alpha iron oxide.]

similar to those on tuffs are much older than those on the latter. The flows with massed buckshot and deep clay subsoil are Middle (and sometimes perhaps Lower) Pleistocene in age.

Hypothesis of Fossil Soil Succession

The following series of soils, characterizing successive terrains, were formed:

(a) Nunawading Terrain. Deep kaolinization and/or bauxitization. Middle Tertiary, mostly Miocene.
(b) Timboon Terrain. Lateritization. Lower Pliocene.
(c) Kraznozem formation. Probably Plio-Pleistocene, i.e. late Pliocene and Lower Pleistocene.
(d) Quaternary duplex soils (including montmorillonite-bearing soils on basalts and tuffs) and loams on younger substrates.

The foregoing changes in type of soil formation are not due simply to differences in the time factor. The marine faunas throughout this period of time, the land faunas

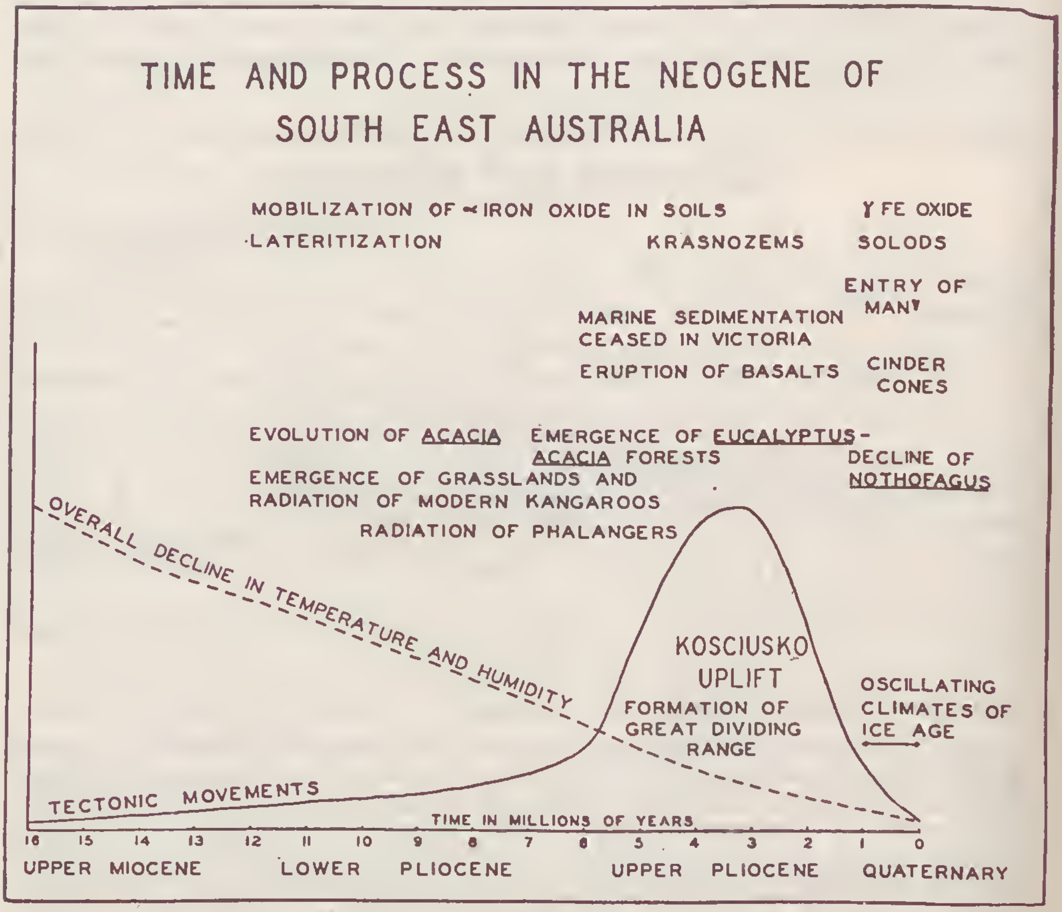

Fig. 8

(Gill 1961c,d) and the results of oxygen isotope palaeotemperature analyses (Dorman and Gill 1958) provide independent evidence of climatic changes. These are summarized in Fig. 8.

If the foregoing hypothesis can be proved, these fossil terrains will enable dating in areas where correlation is difficult or seemingly impossible. Two examples will illustrate the method. The type of Professor McCoy's fossil wombat *Vombatus pliocenus* came from 'hard gold cement' at Dunolly, Victoria. The fossil came from a depth of 50 ft in a mass of secondary carbonate at the bottom of a channel filled with auriferous sands and gravels. It can be shown that this stream system was incised in the Timboon Terrain, and the thick gravels themselves are evidence of the Kosciusko uplift. As the fossil is later than the Timboon Terrain it is later than Lower Pliocene. In that it was found in thick Kosciusko sediments, it probably belongs to the Upper Pliocene or Lower Pleistocene when the main movements took place. Since it is at the very bottom of these sediments, it is probably Upper Pliocene in age.

Another example is the dating of the Rowsley Fault at Bacchus Marsh (Fenner 1918, 1925; Hills 1934; Thomas and Baragwanath 1950). The Timboon Terrain of Lower Pliocene age caps the Rowsley Scarp and is covered in some areas by basalt. The laterite characterizing this terrain could not have been formed with the Rowsley Scarp present, because its genesis depends on alternate water-logging and aeration of the ground that could not take place at such a well-drained site. The fault is accordingly later than Lower Pliocene and probably Upper Pliocene. The basalt is on the uplifted plateau and also infills a youthful valley in the scarp seen at Dogtrap Gully, so the basalt was extruded shortly after the faulting and should also be referred to the Upper Pliocene.

Silica in Soils on Basalts

As there is no free quartz in basalt, it is necessary to explain the presence of quartz in soils on basaltic flows and tuff spreads in W. Victoria. The quartz is of the high temperature variety and is derived apparently from granitic sources. The grains vary in size from the finest silt to waterworn boulders, with much variation in shape and angularity. There are three main mechanisms by which such silica has been emplaced; each mechanism has produced a distinctive type of deposit.

Emplacement by Wind Action

This type of deposit may be recognized by the grain size analysis, which gives a cumulative curve similar to that of loess. Where a soil has an appreciable quantity of rounded quartz grains of silt size, it can be inferred that the deposit has been transported by the wind, as this is the only way in which such material can be sorted to this degree. There exist many loess-like deposits round lakes (Hills 1939, 1940a; Stephens and Crocker 1946; Gill 1953a) and, in addition, there are deposits of this type infilling hollows in the landscape with greater frequency than has been recorded. Some river terraces also consist of loess-like materials interpreted as redeposited loess or materials resembling loess, e.g. the Doutta Galla Silt of the Maribyrnong R. Valley (Gill 1962b).

No grain size analysis has yet placed any of these deposits strictly in the category of loess as now so closely defined; usually the deposits are more clayey (the 'parna' of Butler 1956) or more sandy. On the other hand, many of the deposits are so like loess that visitors from overseas familiar with that material have regarded our deposits as such.

Some of the quartz comes from the wind-sifting of coastal dunes, but the majority comes from the deflation of dry lake floors. At the present time many shallow lakes on the basalt plain dry up in summers of low precipitation and high temperatures, e.g. 12 summers in the past 40 L. Colongulac at Camperdown has gone dry. In drier times, such as the postglacial thermal maximum, such a lake would dry up every summer, and deflation of the lake floor would take place. The considerable volume of dunes on the E. and SE. sides of the lakes is witness to the measure of this movement. During such periods, the playas have been lowered, so extending the life of the lakes, and the material has been supplied for the dust storms that carried the silt-sized silica across the countryside and built up the lunettes and similar structures. The prevailing winds were then NW. in SW. Victoria and not SW. as at present. The more clayey deposits are due to the fretting of mud polygons and the blowing up of the clay as aggregates; the more sandy deposits are due to the addition of saltatory material. For example, at the NE. end of L. Weering there is a good deal of sand in the soil on basalt and this appears to have its origin in saltatory material from the floor of L. Weering.

EMPLACEMENT BY VOLCANIC ACTION

Leeper et al. (1936) have described the distribution at Mt Gellibrand (a volcano) of silica sand in the soil with lines of equal percentage concentric on the crater, the greatest percentages being nearer the vent. We can conclude from this that the volcano is responsible for the emplacement of this silica, or at least for the major part of it. Hanks (1955, p. 13) has recorded silica gravel in a lava flow at Bunker's Hill and four other sites N. of Melbourne; he lists references to earlier records of quartz in basalt in Victoria.

The area covered by the basalt plain of W. Victoria has had great quantities of sand and clay deposited on it. It is, therefore, not surprising that volcanoes breaking through these formations have brought the material to the surface and distributed it with other ejectamenta or in the lava flows. As far as the author's observations have gone, silica is brought up by every volcano, but the amount varies. The volcano Ecklin Hill (Gill 1947) has the greatest quantity observed so far, so much so that in certain layers of the ejectamenta it enhances the value of the material for road-making. Owing to the mechanical activity involved, more silica has been distributed by the explosive than by the effusive volcanoes. Pyroclastic products decompose more readily and so more quartz is present in soils developed on ejectamenta; such silica is characterized by its lack of sorting, and sometimes by its relations to vents.

EMPLACEMENT BY WATER ACTION

Lakes are common on the basalt plain of W. Victoria, but they were far more extensive and more numerous during the wetter and cooler glacial periods of the Pleistocene when there was greater precipitation and less evaporation. Lakes are particularly abundant in the area between the Dividing Ra. and the Otways, because the raising of the Otways caused a general damming of the southerly drainage (Gill 1964). Between the Barwon R. in the E. and Mt Emu Ck in the W. there are few streams but dozens of lakes, often orientated in N.-S. direction. Water washing across the land to these lakes and from lake to lake in wet periods has helped to distribute water-sorted silica across the basalt plain. Where there are high level basalts and low level basalts, e.g. in the Moorabool R. valley near Geelong (Coulson 1938) and in the Hopkins R. valley at Allansford near Warrnambool, silica sand may wash from the sub-basaltic deposits of the higher flows on to the surfaces of the lower flows. Where a valley has been infilled with basalt, sand will wash from the surrounding terrain on to the basalt flow because it occupies the area of lowest relief. Lying on a grassy slope in the rain, one can watch the Lilliputian streams between the grass roots gradually conveying grains of sand downslope. Although the declivity be low, great quantities of quartz grains and other particles can be shifted in this fashion, given geological time and the wetter periods of the past since the basalt was extruded. The range of grain sizes carried and the degree of sorting will depend on the amount of water, its energy, and the distance carried.

Basalt-sediment Interface and Tectonics

In E. Australia, tectonic movements continued through the Cainozoic Era, but there were two maxima associated with the extrusion of the Older Basalts and Newer Basalts respectively (Gill and Sharp 1957). The span of time during which the second period of movements took place was called by Andrews (1910) the **Kosciusko Epoch.** The effects of these movements are widely recognized throughout E. Australia. A similar term is needed for the earlier series of movements; it is proposed that this time interval be called the **Bass Strait Epoch** because Bass Strait was formed (shown by marine encroachments), the Port Philip Sunkland initiated, and the Tamar Graben formed in N. Tasmania (Gill 1962a) at that time.

These two series of movements can be illustrated well at Bacchus Marsh, 35 miles WNW. of Melbourne. Fenner (1918, 1925) worked out the structure, and later Thomas and Baragwanath (1950) extended knowledge of the area. The essential structures consist of—

(1) Two roughly E.-W. faults (Greendale and Spring Ck) that in Lower Cainozoic time formed the Ballan Sunkland.
(2) The roughly N.-S. Rowsley Fault connected with the uplift of the highlands in the upper Cainozoic.

The laterite of the Timboon Terrain can be seen under the basalt on the S. side of the Werribee Gorge. It also caps Table Hill and the hill N. of the Western Highway and W. of Korkuperrimal Ck. Such laterite could not form on the edge of a plateau because the situation would be too well drained. The Rowsley Scarp must have developed, therefore, after the Timboon Terrain laterite formed in the Lower Pliocene. On the Rowsley Scarp at Dogtrap Gully, between Parwan Ck and the Werribee R., basalt infills a youthful steep-sided valley. Therefore, uplift had taken place and this valley had been eroded before the basalt that infilled it was extruded. The Rowsley Fault scarp must have been formed, therefore, prior to the Upper Pliocene and/or Pleistocene basalts, and prior to the ?Upper Pliocene lacustrine deposits at Coimadai (see below) but, being at the same time post Lower Pliocene in age, it was most likely an Upper Pliocene event.

Two remarkable characteristics have been noted about the sediments under the basalt in the Maryborough, Avoca, Huntly and Ballarat districts (Baragwanath 1923, Mines Dept 1937):

(1) The bottoms of the leads have for some miles downstream a rising instead of a falling gradient.
(2) There are widespread lacustrine as opposed to fluviatile sediments.

These two characteristics are no doubt related. The uplift of the Dividing Ra. took place in such a way that the direction of flow of many streams reversed; this led to the ponding of streams and lacustrine sedimentation.

Basalt in Glacial Period Channels

The geological map of Melbourne (published by the Department of Mines 1959) shows basalt flows coming down from more northern eruption centres and occupying the valley of the Yarra R. (see also Hanks 1955). The drainage is southerly and then turns westerly under the influence of the Melbourne Warp (Gill 1961b). Bores and excavations show that the bed of the Yarra occupied by the basalt is graded to a much lower sea level. The basalt extends as far as Spencer St, Melbourne, where excavations for the bridge showed the thalweg to be about 83 ft below present sea level (Gill 1949, p. 39); this is probably part of the channel that reached a depth of 113 ft below sea level at Port Melbourne.

Reid's basalt quarry on Steele Ck at Niddrie, a suburb of Melbourne, shows Newer Basalt occupying a valley crossing the Maribyrnong R. at Braybrook, thus causing a large loop in the river. The thalweg of the stream is a considerable distance below sea level, and even allowing for the earth movements in the time involved, this is probably due to gradation to a lower sea level of a Pleistocene glacial period. The walls of the Maribyrnong R. valley intersect the walls of the fossil valley on the E. and W. limbs of the river loop respectively. On the E. side, near the old tea gardens, fossil vascular plants in position of growth were found in the fossil soil of the former valley wall; the normal river level therefore was below this. At Allansford near Warrnambool, at Port Fairy, and at Portland in W. Victoria there are lava flows in old valleys graded to a lower relative level of the sea.

Aeolianite and Basalts

While the E. coast of Australia is characterized by siliceous sand dunes, the S. coast is characterized by calcareous sand dunes. The Pleistocene limey dunes are lithified into aeolianite. The Riss/Würm dunes in Victoria have only a hard travertine crust, while the older ones are lithified throughout, but the degree of lithification may vary with age, as can be seen in the three superposed dune systems with intercalated fossil soils in the large quarry at the E. end of Albert Park, Warrnambool. The faces of road and rail cuttings through Riss/Würm dunes have to be specially treated to prevent sand flow; on the other hand, the aeolianite of Middle and Lower Pleistocene age is used for building houses and stone walls.

Differing opinions have been expressed whether aeolianite dunes are a product of glacial periods with low sea level (when the continental shelves were bare), or represent times of higher sea level in the interglacial periods. This is surely a false antithesis. As the dunes are a product of coastal processes, the extant dunes on the coast must have been produced when the sea was at or near its present level. Some must have been built during the interglacial periods, e.g. those resting on the Riss/Würm interglacial marine beds that pass up into dunes. On the other hand, there is evidence from bores below sea level and from submarine contours that there are dunes built in the colder times of lower sea level. Such dunes were built successively as the sea advanced and retreated from low glacial to high interglacial positions, and so probably range from interglacial to glacial in age.

At Warrnambool, three snail faunas are preserved in dunes:

(1) Dry facies snails in the aeolianite itself.
(2) Wet facies snails in the intercalated terra rossa soils.
(3) Introduced snails in the mobile dune sands deposited since the system was disturbed by European occupation.

The aeolianite continues far out under the sea and it would be interesting to know if the dunes further out on the continental shelf have a different snail fauna suited to the colder and wetter times.

The basalts of the W. plain vary in their relationships to these dunes, providing evidence of the age of the flows and of past climatic conditions. At Warrnambool, the farthest inland aeolianite rests on the weathered surface of the basalt (Gill 1943), the weathered surface showing the basalt to be somewhat older than the aeolianite. The basalt is at least as old as Lower Pleistocene, because at least two other and older cycles of aeolianite formation can be demonstrated prior to the Riss/Würm interglacial. Similar conditions are found at Portland (Boutakoff 1963). In all places examined, the Holocene mobile dunes overlie both basalts and tuffs.

Marine Deposits on Basalt Plain

Along the coast, aeolianite dunes fringe the basalt plain in many places. Intercalated with these dunes, overlying them, and also in places where dunes do not occur, are marine beds of Quaternary age. The most widespread are beds that are obviously very recent by reason of their lack of consolidation, their unoxidized condition, the extremely good preservation of the shells, the lack of secondary carbonate features such as pipes, and their grading in relation to present coastal structures. Many of these have now been dated by radiocarbon and have been shown to be mid-Holocene in age. Some writers have called such beds storm beaches, but when they occur in enclosed lagoons they cannot be so explained. Such ideas are obviously inappropriate when the ecology of these sediments is studied. The beds are stratified and so must have been laid down below low tide mark, there are fine sediments that storm waves would carry away, there is no flotsam and jetsam, and often bivalves are present in great numbers with both valves still together. Moreover, these beds carry faunal evidence of slightly warmer seas. Conversely, since the post-glacial thermal maximum was a time of greater warmth, higher seas would be expected on the glacial control theory. This theory can be accepted as at least the major factor in sea level change in the Quaternary, as radiocarbon has made it possible to prove that the sea level was low during the times of glaciation on land during the last glacial period.

The alternatives are that these strata have been uplifted by tectonic movement, or have emerged by reason of eustatic changes of sea level. The latter view is favoured because, when allowance is made for difference in tidal range, these beds have emerged to very closely the same amount whether on stable blocks or along sinking coasts of basins where the tectonic vector is downwards. To ask that, whatever the tectonic environment, all these beds in this short space of time should all be elevated to the same amount correct within a foot or two appears to the writer to be a *reductio ad absurdum.**

[* This is part of a world problem which is being studied by a Commission of INQUA with which the ANZAAS Committee for the Investigation of Quaternary Shoreline changes is co-operating.]

Next oldest are beds reaching about 25 ft above present LWM. They are consolidated, oxidized, have been incised below present sea level, have secondary carbonate structures such as pipes, possess faunal evidence of warmer seas, pass below the youngest aeolianite dunes (those with a travertine crust), and are beyond the range of radiocarbon dating. They are believed to be Riss/Würm Interglacial in age, and are useful for providing a minimum date for lava flows that they cover, such as at Port Fairy.

There are evidences of yet older sea levels of Quaternary age overlying the fringe of the basaltic plain, but these evidences are mostly erosional and lack biological dating. The early Pleistocene marine deposits (the Werrikoo Member in the Glenelg R. to Portland area, and the Moorabool Viaduct Sands of the Geelong area) underlie the local basalts.

Lacustrine and Palustrine Deposits

Hollows in the basaltic plain were filled with water and became lakes. Water occupying such areas of negative relief increased their extent by erosion of the banks; because the level of the water was constantly changing, wide areas could be eroded in this fashion. Such water also enlarged the hollows to some extent by solution.* The hollows occupied by lakes have been formed in many different ways. Some are sags in the lava plain. Some are low areas between lava flows. Some are due, like L. Colac, to the blocking of drainage by faults. At Colac, a fault at the S. end of the lake brings up the Cretaceous rocks, and has also uplifted an ancient river bed covered with basalt; a volcano is sited there as well, but this is younger than the underlying lake sediments, so the fault is considered to be the primary cause of lake formation. The hill at the S. end of L. Colac on which the Colac Motel stands is a much eroded and weathered volcano of possibly Lower Pleistocene age. The lake shore section W. of the unnamed creek shows, from below up, a laucustrine bed without tuff, then a lacustrine bed with tuff containing leaves, eucalypt fruits and a few marine shells, and finally a thick bed of volcanic agglomerate. The lacustrine beds prove that L. Colac formerly extended farther S. than at present.

[* Along the coast where basalt outcrops but receives only spray action and not direct wave action, the rock may be honeycombed, demonstrating solution by sea water.]

At Camperdown, S. of L. Colongulac there is a complex of volcanoes connected with the formation of that lake. As far as it has been elucidated, the succession of events is as follows:

(1) An effusive volcano S. of Camperdown (Gill 1953a, p, 28) extruded lava flows that blocked the drainage. The surfaces of the basalt flows on the S. side of the lake dip N. and pass under the lake floor.
(2) The explosive volcanoes Gnotuk, Bullenmerri, and Leura deposited ash over the terrain (Hampden Tuff), partly infilling the lake. The scoriaceous ejectamenta forming Mt Leura represent a later event.
(3) In the mid-Holocene tuffaceous sediment from the lake floor was blown up into dunes (Colongulac Parna), thus deepening the lake a little. Basalt flows on the E., N. and W. banks formed the original limits of the lake in those directions.

Other lakes occupy volcanic craters (e.g. Bullenmerri, Burrumbete, Gnotuk, Terang, Keilambete, Wangoom), while others again occupy hollows between aeolianite dune systems and the former coast (e.g. Gillear and Bridgewater).

Lake basins gradually become infilled and form swamps; indeed a given catchment may oscillate between swamp and lake according to climatic conditions or even seasonal conditions. Pejark Marsh at Terang is probably a lake that has become a swamp. Some old lakes associated with the lava plain accumulated sediments but were then drained and dissected. An example of such a lake is represented by the lacustrine deposits at Coimadai (Officer and Hogg 1897-8, O'Donoghue 1916, Summers 1923, Coulson 1924, Keble 1925). Two formations are represented; for which names are here proposed:

Upper **Alkemade Siltstone** (after the type locality of Alkemade's Quarry).
Lower **Coimadai Dolomite** (the quarried rock).

In 1958, the following section was measured on the E. wall of Alkemade's Quarry:

13′ 0″	Claystone and siltstone, laminated in lower part.
9″	Limestone.
4″	Ferruginous sandstone.
1′ 3″	Laminated claystone with plant fragments and ostracods.
1′ +	Dolomite. The beds above this layer constitute the Alkemade Siltstone which forms a face at an angle of 35° to the horizontal, while the underlying limestone maintains a vertical face. Material slipping from the siltstone formation obscured the limestone below and so the section was continued a little farther N. whence the plant bed could be easily followed.
18′ 0″	Banded dolomite.
3″	Speckled fawn sand.
8″	Thin bands of calcareous siltstone to silty limestone.
1′ 4″+	Limestone breccia. The above four beds constitute Coimadai Dolomite.

The limestone has yielded the bones of marsupials, some of which are different from the usual Pleistocene faunas and are thought to be older.* Fenner's explanation (1918) of the formation of the lake by the Bullengarook lava flow blocking the drainage is untenable because the base of the lava flow is higher than the deposits in the valley.**

[* Dr Isabel Cookson and Mrs Kathleen McWhae examined separate samples of the carbonaceaus siltstone, but neither was able to discover pollens or spores with which to date the bed. A *Casuarina* cone has been found in the limestone, but this does not help dating.]

[** The Coimadai Fault of Fenner (1918) probably does not exist since the platform cut on the Ordovician bedrock is at similar elevations on the N. and S. sides of the Coimadai valley.]

The following reconstruction is suggested:

1. Uplift of the highlands resulted in streams cutting valleys in higher areas; the Coimadai valley was probably cut at this time.
2. Alluvial fans from the uplifted country to the W. and N. of this valley spread out, blocked the drainage and formed the lake. This hypothesis accounts for the great thickness of clayey sands under the Bullengarook basalt, and the apparent absence of stream gravels, in this area. A stream probably drained overflow from this lake and ran S. to the Werribee R.
3. The Bullengarook basalt flowed down from the N. and infilled this stream bed, but did not infill the Coimadai valley because it was already infilled with sediments.
4. Twin streams marginal to the basalt cut down to form the valleys of Goodman's Ck and Pyrete Ck.

A feature of the Coimadai Limestone is the presence of large collapse structures with dips commonly as much as 20-25°, but as high as 55°, that occurred before the Alkemade Siltstone was emplaced. The simplest explanation seems to be that at times the streams draining the area cut down faster than the piedmont deposits filled the valley mouth, so that the lake was temporarily lowered. The low level of the water would then cause solution and erosion low in the formation and so initiate collapse. Later, with further uplift, the sediments from the highlands completely sealed the valley, and the clayey upper formation was deposited. Then the Bullengarook basalt formed a shield over the outwashed clayey sands, and streams cut back along its margins without being overloaded. In time the stream on the NE. side cut back far enough to drain the Coimadai lake and then incise the deposits. Remnants of the lacustrine beds remain round the valley at Alkemade's, Hjorth's and Davies's quarries, indicating that they once existed right across the valley, as one would infer. The amount of erosion performed by so small a stream is indicative of a long history. Until recently there were active springs at Alkemade's, so solution by spring waters may have been an alternative or additional factor causing collapse.

Fluorine tests have been made on a series of bones from beneath the basalt from Ballarat to Coimadai, and while evidence of high fluorine content on its own proves little, it strengthens the case for giving these beds some antiquity. On the above reconstruction, the formations at Coimadai are pre-basaltic and not post-basaltic. As the Rowsley Fault is epi-Timboon Terrain (Lower Pliocene) in age, and the Coimadai deposits followed close on the faulting, an Upper Pliocene age for the Coimadai Limestone and Alkemade Siltstone seems likely. The upper Pliocene has a time span of 6 or 7 million years and the Quaternary only one million so, considering the succession of events to be fitted in, it is more likely that the deposition of the lacustrine deposits at Coimadai took place in the Upper Pliocene than in the Pleistocene.

Another notable feature of the limestone at Coimadai is that it is recrystallized. A similar recrystallized limestone, the Lara Limestone, occurs to the SW. near Geelong, and it is also related to the basalts and to the group of faults of which the Rowsley Fault is the main one. However, the Lara Limestone overlies the basalt, but as it has a similar relationship to the movements dated as Upper Pliocene, it is also considered to be of this age. If one distinguishes between the fossils found in the limestone and those found in cavities in the limestone, this also has a fauna that is older than the accepted Pleistocene one. The *Diprotodon* found in the Lara Limestone is not the Pleistocene *D. optatum* but the related *D. longiceps* (Keble 1945). A *'Unio'* collected from this limestone by Dr G. B. Pritchard is stated by Dr D. McMichael to be a new genus. A limestone similar to the Lara Limestone occurs on the S. side of Corio Bay, forming Limeburners' Point. It would appear that this limestone is part of the same formation or series of formations infilling a valley, the drainage of which was blocked by Upper Pliocene earth movements. The formation of Corio Bay is a later, aparently Pleistocene event; it is earlier than Holocene because incision of the valleys occurred during the last low sea level.

Lacustrine Deposits and the Latest Eruptions

From a great deal of available information, the relationship as seen at Pirron Yallock will be described. This village is W. of Colac at the S. end of L. Corangamite. Even at the height of the 'creeping lakes' advance of lake level in the past 10 years, the water did not come within 6 to 10 ft. of this platform. The village is on the Pirron Yallock Ck which is marginal to the Stony Rises newer basalt flows (cf. Skeats and James 1937, Hills 1939). Some years ago when a new bridge was being built across the creek at the Princes Highway, bedded tuffs were exposed showing well-formed ripple marks at a number of levels (Fig. 9). A section showing the tuff can still be seen just downstream from the bridge. Skeats and James (1937) recorded the brackish water snail shell *Coxiella* in tuffs in this area, pointing out that they indicated a lake level 5 ft or so higher than the present. Since the tuffs are spread round the Vaughan Is. volcano at the S. end of the lake, that must be their source.

Stony rises are overlain by parna dunes on the E. side of L. Corangamite in the Dreeite area. The stony rises (in the Corangamite area at least) are thus older than the Vaughan Is. eruption and older than the parna dunes. The former was a time of higher lake level and the latter a time of dryness. Evidences for recent changes of

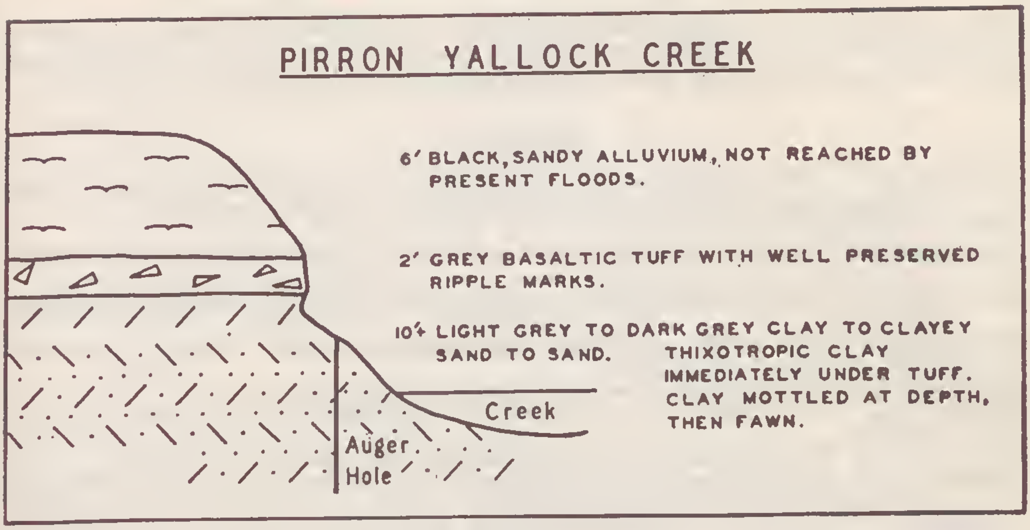

FIG. 9

this kind are common on the basalt plain, and so are a function of climatic change rather than local conditions.

The Lava Plain and Parna Dunes

During the mid-Holocene drier period (postglacial thermal maximum—Gill 1955) most if not all the surficial lakes (as against the deeper crater lakes) dried up, at least in the summer, so that the floors were desiccated and the dunes on the E. and SE. shores built up (Hills 1939, Stephens and Crocker 1946, Gill 1953a). Hills (1940) proposed the geographical name **lunette** for the new-moon shaped dunes so characteristic of the round lakes. There is a tendency to call all parna dunes lunettes, but to do this will rob the term of its distinctive meaning. Of recent years, the term **loess** has been stripped of its genetic implications and specifically defined as grains falling within a given grain size analysis. As far as is known, only air transport can bring about sediment of such sorting. This is therefore a good term, being solely descriptive by definition, yet having useful genetic implications. Butler (1956) has pointed out that the dune materials round many lakes is too clayey to be called loess in its modern definition and so he introduced the term **parna** for 'aeolian clay'. Such sediments could not have been blown through the air as separate entities or they could not have formed these dunes. It is implied that they blew up as aggregates, as can be seen happening now in dry years in small measure. This term also is in danger of losing its distinctiveness by being used for any materials found in such dunes, i.e. given a genetic significance. By definition, parna is a material of much finer grain size than loess. As parna always has much carbonate in it, this chemical constituent may also help to keep it in aggregates. A fabric analysis of material found blowing at the present time might yield helpful information.

Conclusion

As the volcanic rocks of the W. District lava plain have been emplaced at many times from the Upper Miocene to the Upper Holocene, there are numerous interfaces both below these rocks and above them that yield helpful information regarding time and process. Further radiocarbon datings for the end of this period of time, and potassium/argon datings for the earlier basalts and tuffs are needed.

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